International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN(P): 2249-6890; ISSN(E): 2249-8001
Vol. 8, Issue 4, Aug 2018, 1001-1012

ENHANCEMENT OF THERMAL AND PERFORMANCE OF MULTIPLE PASS HEAT EXCHANGER USING NANOPARTICLES

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ABSTRACT

Thermal and hydrodynamics performance of1shell and 2-tubes heat exchanger with different concentrations of ethylene glycol, copper and alumina as nanofluid have been investigated, theoretically and numerically. The heat exchanger is 1shell- multiple pass with eight bend pipes. The hot water is flowed in the bend tubes and cooled by water with different types of nanoparticles in the shell flow. Three different types of nanoparticles, which are (ethylene glycol, copper and alumina), have been used in water as a working nanofluid. The results show that; the water-copper and water-alumina nanofluid have the best performance enhancement of the heat exchanger than ethylene glycol with effectiveness 0.175. Additionally, the minimum friction factor appears when the copper and alumina particles used. The numerical results are in a good agreement with theoretical results and the maximum percentage error of the effectiveness equal to 4%.

KEYWORDS: Heat Exchanger, Shell and Tube, Nanofluid, Effectiveness & Friction Factor

Received: May 29, 2018; **Accepted:** Jul 16, 2018; **Published:** Aug 10, 2018; **Paper Id.:** IJMPERDAUG2018104

Original Article

NOMENCLATURE

B	Baffle spacing [m]
b_f	Basic fluid
C	Heat capacity rate [kJ/(kg.K)]
C_p	Heating capacity [kJ/(kg.K)]
C_r	Ratio of heat capacity rate
D	Diameter [m]
F	Friction factor
H	Heat transfer coefficient [kW/(m2.K)]
u_m	Mean velocity [m/s]
K	Thermal conductivity [kW/(m.K)]
L_t	Tube length [m]

NTU	Number of heat transfer unit
n_f	Nanofluid
Ss	Stainless steel

Greek Symbols

$\o$	Volume fraction
ε	Effectiveness
μ	Dynamic viscosity [Pa.S]
ρ	Density [kg/m3]

Subscripts and Indexes

I	Inner
O	Outer
S	Shell
T	Tube

INTRODUCTION

Heat exchangers are devices or systems, where, energy is transferred from high temperature fluid to low temperature fluid. The working fluid flow could be liquids or gases or both of them as mixtures. Shell and tube heat exchangers are the most dominant. When a heat exchanger is placed into a thermal transfer system, a temperature drop is required to transfer the heat. The magnitude of the temperature drop can be decreased by utilizing a larger heat exchanger, which means extra cost of the heat exchanger, in addition to increase in the pumping power is expected due to the increase in pressure drop. Therefore, the economic parameters are important in a complete engineering design of heat exchange equipment. Mostly, in the engineering fields, the basic fluids, which are using to transfer the heat, are water, engine oil, refrigerants, ethylene glycol etc.

Many researches made on modification performance of the heat transfer on heat exchangers surfaces, but still the main improvements in cooling efficiency have been unsurpassed, because of the poor thermal properties of conventional heat transfer fluids. The thermal conductivity improvement plays a vital role in the modification of any energy-efficient heat transfer fluids. One of the latest improvements in heat transfer flow are the use of nanometers particles ($1e^{-9}$ m) as mixing particles in the basic fluid, which is a method of improvement heat transfer in the devices [1]. The objective from using metal particles is increasing the physical thermal properties of working fluids. The nanotechnology technique is used in hanging nanomaterials in heat exchange between two fluids flow to enhance the heat transfer coefficient of the base fluids. The nanomaterial in heat transfer fluids increase the effectiveness by increasing thermal conductivity of the heat transfer fluids, and consequently enhanced the heat transfer characteristics of the heat transfer system. Nanofluids with appropriate selection of the base fluid type, as well as appropriate selection of the nanoparticles in terms of material, size, shape, and concentration in the base fluid can perform much better than the conventional heat transfer fluids [2].

Several studies have achieved performance enhancement of heat exchanger by using conventional fluids or Nanofluids. A different analysis is used to understand the heat transfer in the thermal applications. Azari1 et al [3] studied experimentally and numerically the effect of nanoparticles with water flow inside pipe, under different physical properties and constant heat flux. These CFD results were matching with the experimental results with increasing Reynolds number as supporter to Nusselt and Prandtl numbers.

Yimin Xuan et al [4] studied the treatment methods of nanofluids and the history of their development. Several patterns of nanomaterials have been created by mixing of powders in nano phase with fluids, which reveals the possibility of practical application of the nanofluid. They found that nanofluid shows great potential in enhancing the heat transfer process. One reason is that, the suspended ultra-fine particles remarkably increase the thermal conductivity of the Nanofluid. The volume fraction, shape, dimensions and properties of the nanoparticles effect on the thermal conductivity of nanofluids. The hot-wire method has been used to measure the thermal conductivity of Nanofluids. The measurement results illustrate that the thermal conductivity of Nanofluids remarkably increases with the volume fraction of ultra-fine particles. Sidi El Be et al [5] studied the effect of different concentrations of alumina as nanoparticles with Ethylene Glycol and water. They used two apparatus for the tests, which are a constant heated pipe with parallel coaxial and heated disks.

Jaafar et al [6] studied experimentally the convective flow heat transfer and flow properties of nanoparticles. It is consisting of water with different volume fractions of alumina nanofluid in range between 0.3–2%, flowing inside a horizontal shell and tube heat exchanger under high Reynolds number. The results show that the value of thermal heat transfer coefficient of nanofluid is near than that of the base liquid at same inlet mass flow rate. The heat transfer coefficient of the nanofluid increases, when the inlet mass flow rate increase and the volume fraction of the Al_2O_3nanofluidincrease. However, increasing the volume concentration causes increasing in the viscosity of the nanofluid leading to increase in pressure drop. Alpesh at al [7] focused on the comparative study between multi nanomaterials mixing with water. Experimental work had been achieved with different types of nanoparticles concentrations of alumina, copper, and titanium trioxide. The results show that the cost of nanoparticles manufacturing is important for developing engineering designs based on the work for researcher groups, and the general analysis to guide this effort should be modified. Yogitha Seerapu et al [8] reported a comparison study in the heat exchanger, which have two-pass tube and one shell. The comparison was between water as main fluid and mixing water with different concentrations of Ethylene glycol (50%, 25%). The boundary conditions were at constant temperature for both cases. The results showed higher effectiveness and long mean effective temperature for nanofluid compared with pure main fluid. Experimental investigation made by Davarnejad et al [9], for turbulent flow inside a tube with TiO_3nanoparticles. Different dimensionless parameter have been used in their study which are; Reynolds number (8000 to 51000), and TiO_3 concentrations were (0.002 to 0.02). The result shows that, when Reynolds number and nanoparticles concentrations increase, the Nusselt number increases. The study shows that a good agreement between the experimental and the simulation results. Razvan-Silviuet al [10] performed a CFD study for double pipe heat exchanger with alumina as nanoparticles composited in water. The dependency of Nusselt number on the patterns of the flow and limits of temperature was observed. The concentrations were 1% to 50%. In addition, they reported a higher heat transfer coefficient with increment in nanoparticles concentrations. Chavda et al [11] studied the effect of different conductance of nanoparticles such as metal, carbides and oxides, while basic fluids were water, oil and ethylene glycol. They found that the shape and volume of nanoparticles has a significant factor on the performance of heat exchanger. Mushtaq et al [12] investigate a numerical study for heat exchanger with micro size. Different concentrations of alumina and copper are used at different ranges between 1% and 5%. The results were

increased thermal performance of cooling nanofluid without any increasing in pressure drop. Also, they found that the increasing in flow rate of nanofluid do not share in increasing of performance of heat exchanger, as well as they found the higher conductance of nanoparticles work as supported for higher efficiency to the heat exchanger. Jongwook Choi et al [13] studied a numerical simulation of water with alumina as nanoparticles in side U-tube pipe. The flow was laminar and the mathematical technique was FV method. The CFD results show an increasing in the average Nusselt number and Prandtl number with increasing in Reynolds number. Also, they found that the average Nusselt number was higher in the bend, due to the reverse flow, as well as the large amount in pressure drop due to increment in nanoparticles concentrations. Lee [14] has performed a computational fluid dynamic investigation for different concentration of alumina and copper. The concentrations selected to be between 0.5%- 3%. All the working nanofluid properties increase when the concentration increases, except the specific heat capacity, which decreases. Additionally, a significant effect is inward increasing of efficiency of heat exchanger at water, with copper particles rather than alumina particles. Sharifi et al [15] investigated numerically and experimentally the effect of alumina as nanoparticles with water. The result showed that, when Reynolds number increased, the heat transfer coefficient increased. Rambabu et al. [16] performed an experimental study. They considered adding titanium dioxide as a Nano additive with water as a primary fluid in shell and tube heat exchanger. For different nanofluid concentrations, they observed a sensible increase in heat transfer rate. Recently, many researchers studied shell and tube heat exchanger with/without nanofluid [17-19].

The objective of the present work is to investigate the analysis of heat transfer and hydrodynamic parameters for multiple tube in the shell heat exchanger by flowing water, ethylene glycol, and compare the results using water-based nanofluids (copper and alumina particles).

PROBLEM DESCRIPTION

The thermal applications of heat exchangers may contain number of flow passes. One-shell, with two-flow tube passes heat exchanger is illustrated in the present study as shown in Figure 1. The hot water enters the pipes of the heat exchanger (8 pipe with two pass) at constant temperature (350K). The hot water is cooled by a nanofluid flow, which enters the shell at constant temperature, equal to 283 K.

Different working fluids used in the shell as cooling fluid are (water100%, Ethylene glycol $C_2H_6O_2$ with concentration 25%, 50%, 75%, 100%, water-based nanofluid of copper Cu 1%, 2%, 3% and alumina Al_2O_3 with concentration (1%, 2%, 3%). Three-dimensional model is used with counter flow as shown in Figure 1, with boundary conditions. The specifications of the heat exchanger are presented in Table 1.

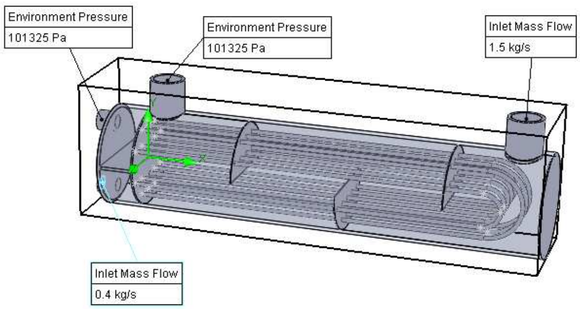

Figure 1: Three Dimensional of 1-Shell 2-Tube Heat Exchanger with Boundary Conditions

Table 1: Specifications of the Heat Exchanger

Value	Dimension
10 mm	Inner tube dia.
12 mm	outer tube dia.
80 mm	Inner shell dia.
100 mm	Outer shell dia.
8	Tube number
298 mm	Baffle spacing
1160 mm	length

MATHEMATICAL RELATIONS

The main purpose of this work is to enhance thermal and performance of multiple pass heat exchangers using nanofluid. Three-dimensional simulation software (Solid Works 2016) has been chosen in this study. The behavior of the performance of heat exchanger depends on new thermo physical properties of Nano fluids, **[14].**

The following equations are considered to evaluate the new properties of working fluid (Nanofluid):

$$\rho_{nf} = (1-\emptyset)\rho_{bf} + \emptyset\rho_p \quad (1)$$

$$Cp_{nf} = (1-\emptyset)Cp_{bf} + \emptyset Cp_p \quad (2)$$

$$\mu_{nf} = \mu_{bf}(123\emptyset^2 + 7.3\emptyset + 1) \quad (3)$$

$$k_{nf} = k_{bf}(4.97\emptyset^2 + 2.72\emptyset + 1) \quad (4)$$

The efficiency is the most common factor, which measures the performance of the heat exchanger. Besides that, it represents the indicator of transferring an amount of thermal energy from hot flow with high temperature to another cold flow at low temperature. The NTU is calculated through the boundary temperatures at the inlet and outlet flow conditions. For CFD simulation, the temperatures at the shell and tube fluid inlets are specified and the temperatures at the outlets can be easily calculated. The relation, which will be used to determine the efficiency of heat exchanger, is defined as follows:

$$\varepsilon = \frac{performedheattransfer}{maximumheatcouldbetransfered} \quad (5)$$

$$\varepsilon = \frac{C_h(T_{hot,in} - T_{hot,out})}{C_{min}(T_{hot,in} - T_{cold,in})} \quad (6)$$

Mean velocity and Reynolds number for shell and tube can be calculated as follow:

$$u_m = \frac{4m^{\cdot}}{\pi \rho D_i} \quad (7)$$

$$Re = \frac{\rho u_m D_i}{\mu} \quad (8)$$

$$f = \frac{64}{Re} \text{ for laminar,}$$

$$f = \frac{0.316}{Re^{0.25}} for\text{turbulence} \quad (9)$$

The theoretical relations, which are used for validation of simulation solution, are: **[20]**

The number of transfer units (NTU)

$$NTU = \frac{UA}{C_{min}} \tag{10}$$

$$U = \frac{1}{RA} = \frac{1}{[\frac{1}{\pi L}\left(\frac{1}{h_{it}D_{it}} + \frac{\ln\left(\frac{D_{ot}}{D_{it}}\right)}{2k_{ss}} + \frac{1}{h_{os}D_{ot}}\right)]} \tag{11}$$

$$h = \frac{kNu}{D} \tag{12}$$

$$Nusselt = \frac{\left(\frac{f}{8}\right)(Re-1000)Pr}{1+12.7(\frac{f}{8})^{0.5}(\mathrm{Pr}^{\frac{2}{3}}-1)} \tag{13}$$

$$\varepsilon = 2\left\{1 + C_r + \sqrt{1 + C_r{}^2}\,\frac{1+\exp\left(-NTU\sqrt{1+C_r{}^2}\right.}{1-\exp\left(-NTU\sqrt{1+C_r{}^2}\right.}\right\}^{-1} \tag{14}$$

While, $C_r = \frac{C_{min}}{C_{max}}$

The general conservation equation of mass, Navier–Stokes equations of momentum and energy governing equations of the fluid flow in the straight and curved tubes, can be written as follows:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = 0 \tag{15}$$

$$\frac{\partial \rho u_i}{\partial t} + \frac{\partial}{\partial x_j}\left(\rho u_i u_j\right) + \frac{\partial p}{\partial x_i} = \frac{\partial}{\partial x_j}\left(\tau_{ij} + \tau_{ij}^R\right) + S_i \tag{16}$$

$$\frac{\partial \rho H}{\partial t} + \frac{\partial \rho u_i H}{\partial x_i} = \frac{\partial}{\partial xi}(u_j\left(\tau_{ij} + \tau_{ij}^R\right) + q_i) + \frac{\partial p}{\partial t} - \tau_{ij}^R\frac{\partial u_i}{\partial x_j} + \rho\varepsilon + S_i u_i + Q_H \tag{17}$$

MESH GENERATION (CFD ANALYSIS)

The CFD Analysis using different numerical approaches and a number of computational techniques, in order to solve and analyze problems that contain heat and fluids flow has been used in this work. Due to the contact between solid and fluid, the calculations require conjugate heat transfer calculations by the boundary conditions, and initial conditions between different surfaces, which are done by the Solid Works. The computational mesh generated by the flow simulation, as solid cells, fluid cells and partial cells in the computational domain, as well as the sides of cells are perpendicular to the specified axes of the Cartesian coordinate system, and is not fitted to the solid/fluid interface. As a result, the solid/fluid interface cuts the near-wall mesh cells. In spite of that, due to special measures, the mass and heat fluxes are treated properly in these cells. Three dimension mesh of the heat exchanger model presented in Figure 2. The number of cells mesh in this simulation have been used as; fluid cells (146710), solid cells (86270) and partial cells (65341).

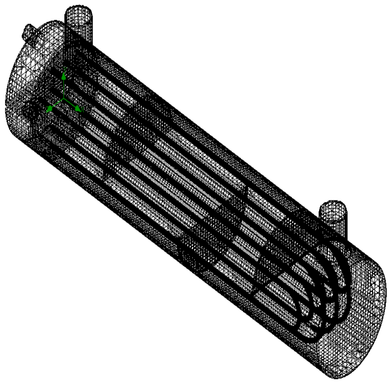

Figure 2: Mesh Generation for 3-D Computational Domain

RESULTS AND DISCUSSIONS

Investigations were carried out by single-phase model in Solid Works for multiple shell and tube heat exchanger. Different nanoparticles with different concentrations were used in the shell flow to improve different parameters for the performance of heat exchanger. The comparison of the performance achieved between water, ethylene glycol, water-copper Nanofluid, water-alumina Nanofluid, as well as the theoretical results.

Concentration Effects on the Average Outlet Temperature

Figure 3 shows the effect of different concentration fluids on the average outlet temperature of tube flow. In Figure 3a**,** when the concentration of ethylene glycol increases (25%, 50%, and 75%), the average outlet temperature also increases. While for the pure water (the concentration of ethylene glycol equal to 0%), the outlet of tube temperature is equal to 339.4K.

The figure3b shows the effect of water-copper Nanofluid (1%, 2%, and 3%) on the average temperature of tube flow. Itis observed that, the increasing in the concentration led to increase in the outlet tube temperature untilit reached the maximum value (338K), but this value is accepted, when it is compared with ethylene glycol concentrations. The minimum outlet temperature appears when the concentration of the copper equal to1%. Comparing with using only water as working fluid, all copper concentration in the Nano flow is decreasing the outlet tube flow temperature, which means a significant enhancement achieved in the heat exchanger.

Also, Figure 3c shows the effect of water-alumina Nanofluid (1%, 2%, and 3%) on the average outlet tube temperature. It is observed that the behavior of alumina concentration is differed than in ethylene glycol and copper concentration. The increase in alumina concentration led to decreasing the average outlet tube temperature, and that happened because of the high heat capacity of water-alumina Nanofluid compared with other Nanofluid.

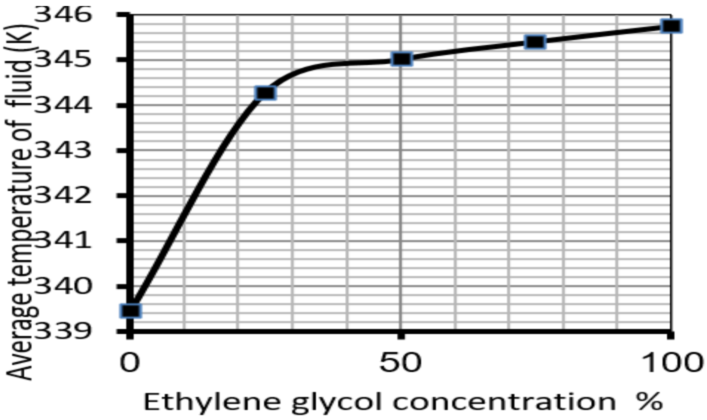

Figure 3a: Average Outlet Tube Temperature for Different Ethylene Glycol Concentrations

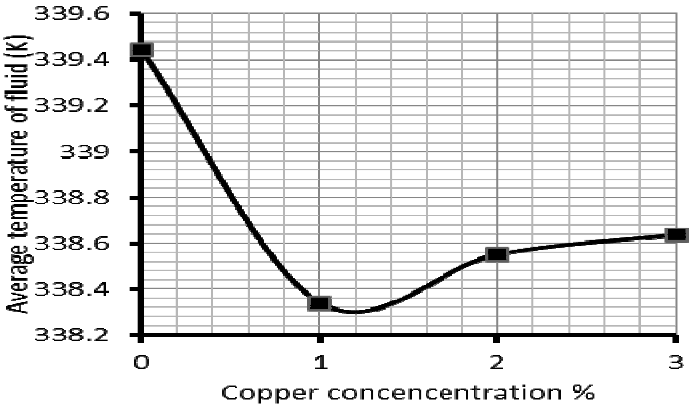

Figure 3b: Average Outlet Tube Temperature for Different Copper

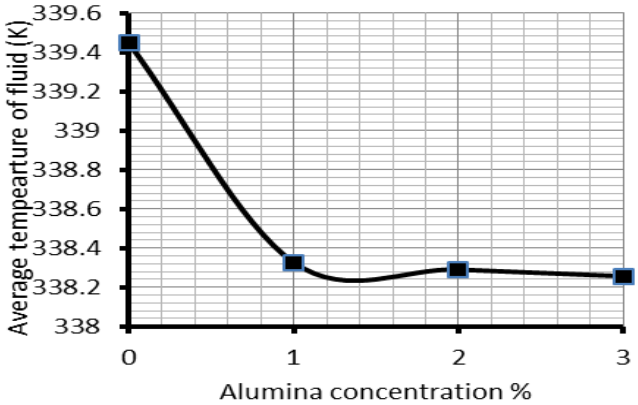

Figure 3c: Average Outlet Tube Temperature for Different Alumina Concentrations

Concentration Effects on the Effectiveness

To obtain the efficiency of heat exchanger, two methods have been used to calculate the effectiveness of heat exchanger. The theoretical and simulation solution are used to evaluate the performance of the heat exchanger with nanofluid in the shell flow. Figure 4a shows the theoretical and simulation results of the heat exchanger when used ethylene glycol with different concentrations (25%, 50%, and 75%). It is clear that the effectiveness decreases with

increasing the ethylene glycol concentrations due to increase theaverage outlet tube temperature, also the theoretical results are matching with simulation results with maximum error 4%. The maximum effectiveness (0.08) at 25% concentration and minimum (0.06)at 75% concentration which are less than the effectiveness of water (0.157)when working alone as shell fluid.

Figures 4b and c shows the effectiveness, which is calculated theoretically and numerically by using a simulation software. The result shows that, when the copper/alumina concentrations increase, the heat exchanger effectiveness increases until the concentrations around 1%, and then decreases with increasing of the copper/alumina concentrations. Both of the theoretical and the simulation results have the same behavior with maximum error about3%.

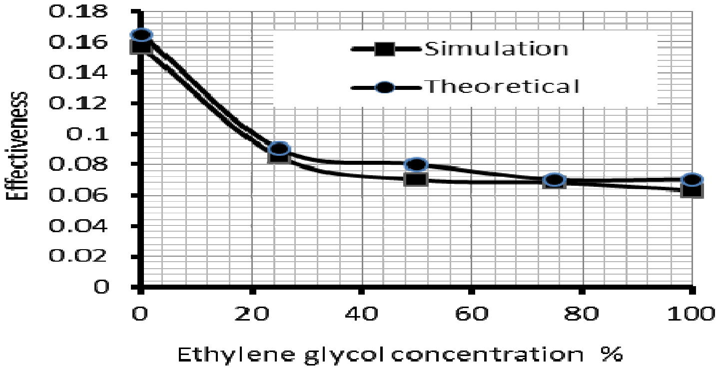

Figure4a: Theoretical and Simulation Effectiveness for Different Ethylene Glycol Concentrations

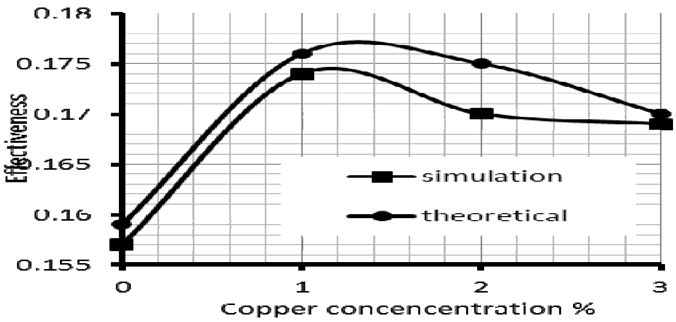

Figure 4b: Theoretical and Simulation Effectiveness for Different Copper Concentrations

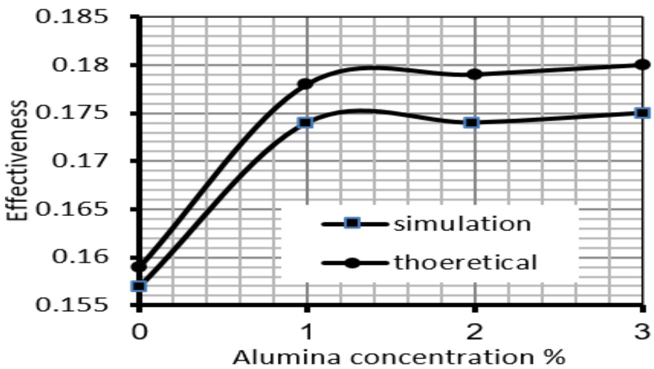

Figure 4c: Theoretical and Simulation Effectiveness for Different Alumina Concentrations

Concentration Effects on Friction Factor

The change of base fluid (water) properties by additives (ethylene glycol) or nanoparticles (copper, alumina) is not a constraint on the improvement of thermal performance only, it also effects on the hydrodynamic parameters too, such as friction factor. Figure 5a presented the results of the friction factor with ethylene glycol concentration. It is increased when the ethylene glycol concentration increased until reaches the maximum value about (0.31) and then decrease that happened due to the mixture properties. Figure 5b presents the result of the cases using copper nanoparticles with water as working nanofluid in shell. The friction factor decreases when the copper concentrations increase until reaches the minimum value (0.037) when copper concentrations equal to 3%. Same behavior can be seen when using copper nanoparticles as shown in Figure 5c**.** Also, it can be seen, the value of friction factor remain constant (0.04) after the alumina concentration increase more than 2%. These values of friction factor depend on Reynolds number, whereas the increasing in the Reynolds number friction factor decreases. All above changes depend on the new base fluid properties, when additives or nanoparticles present.

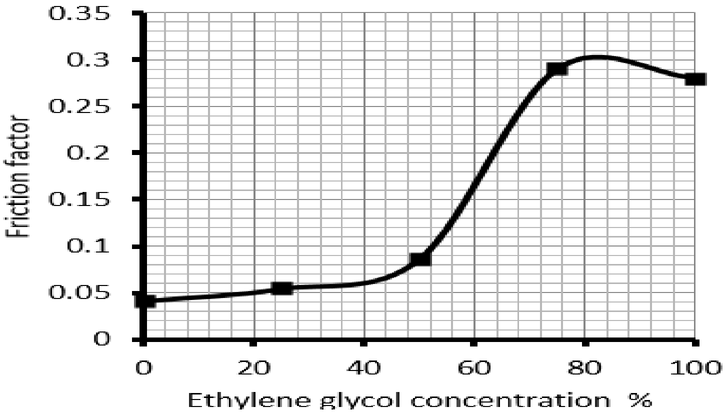

Figure 5a: Effect of ethylene Glycol Concentration on the Friction Factor

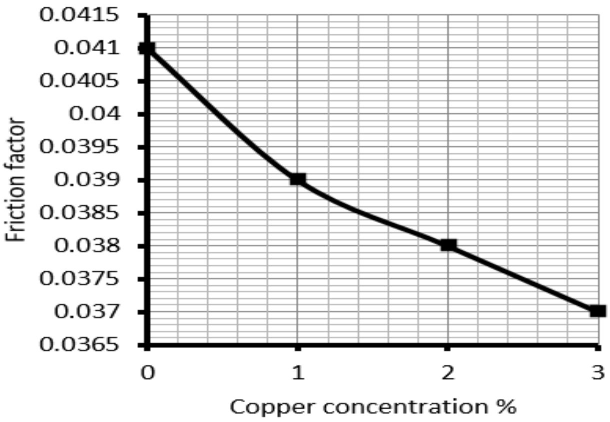

Figure 5b: Effect of Copper Concentration on the Friction Factor

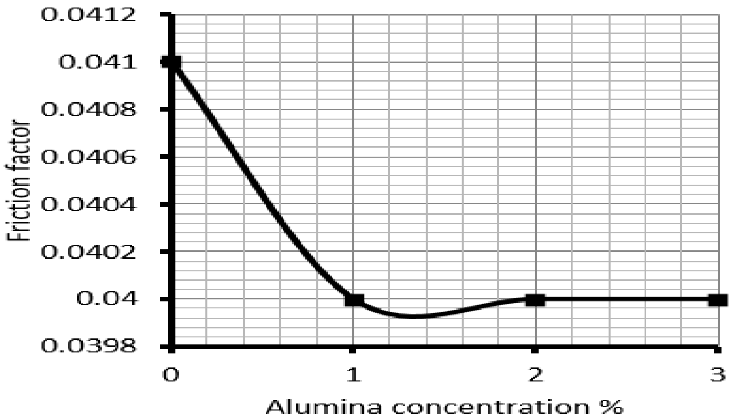

Figure 5c: Effect of Copper Concentration on the Friction Factor

CONCLUSIONS

The current work presents theoretical and numerical simulation of enhancement thermal and performance of multiple pass heat exchanger using nanoparticles using finite element method. The following conclusions can be drawn from the results of the present study:

- The water-alumina nanofluid has the lowest average outlet temperature with different concentrations compering with water-copper nanofluid and ethylene glycol. In addition to the effectiveness that remains constant due to alumina properties.
- The water-alumina nanofluid has the lowest friction factor compared with the other flow of water-copper nanofluid and water-ethylene glycol.
- The ideal concentration of copper concentration and alumina is 1-2% for the present work.
- Single model used in the study satisfied the theoretical results, with maximum error 4%.

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